Environmental Regulation and Firm Efficiency: Studying the Porter Hypothesis using a Directional Output Distance Function•

by

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Abstract.

The purpose of this paper is to suggest a procedure to empirically test the Porter hypothesis. This hypothesis argues that environmental regulation not only increases environmental quality, but also brings the polluting producers information that makes them more resource efficient, as well as able to develop new technologies. Specifically, the hypothesis tested is whether there is a positive significant correlation between producers' technical output efficiency and environmental regulation. Efficiency is first estimated using a methodology where the production technology is represented by a directional output distance function, which credits a simultaneous expansion of market goods and contraction of emissions. Then, by regressing the obtained efficiency scores on an index that approximates environmental regulatory intensity, the Porter hypothesis is explicitly tested. The test procedure is applied on 12 Swedish pulp plants during 1983-1990. The result shows no support for the Porter hypothesis.

Key words: Porter hypothesis, environmental regulation, technical efficiency, parametric directional output distance function

JEL codes: C61, D21, D24, L51, Q53

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1 INTRODUCTION

Environmental problems, originating from processes of manufacturing market goods, are being discussed in public debate and there is a growing interest in the effects of different instruments of environmental control. The welfare consequences of environmental regulation depend, to a large extent, on how economic agents adjust their behavior. This paper concentrates on how producers respond to environmental regulation. According to standard neoclassical theory, there may be two forces at work simultaneously. First, there is a 'crowding-out' effect, i.e., environmental investments take place at the expense of productive capital, which may lower productivity growth. Second, the productivity level is instantly lowered when producers are forced to use more of their resources to abate rather than produce income-generating market goods. However, this idea has been questioned during the last decade.

Porter (1991) introduces the idea that has come to be known as the *Porter hypothesis*. He asserts that producers actually may benefit and gain competitiveness from being subject to environmental regulation. This idea of a possible 'win-win' option, i.e., that environmental regulation both brings private net gains and a cleaner environment, is of course popular among environmentalists and policy-makers, since it spares one from the difficult 'trade-off' between environmental and other economic goals. In Porter and van der Linde (1995) the arguments for the hypothesis are developed further. The dominating argument is that environmental regulation brings information and makes producers aware of certain opportunities, e.g., of improving private productivity. The productivity change is divided into an efficiency change and a technological change. Porter and van der Linde (1995) argue that properly crafted environmental regulation can serve several purposes, e.g.: "(…) regulation signals companies about likely resource inefficiencies and potential technological improvements" (p. 99).

The purpose of this paper is to suggest a procedure to test the Porter hypothesis empirically. The procedure is general in the sense that it can be applied to any production process at the plant, industry, or country level. Specifically, it focuses on the efficiency part of the hypothesis by suggesting a procedure for testing whether there is a significant positive correlation between producers' technical output efficiency and environmental regulatory stringency.[1]

As a first step, technical output efficiency is estimated for each producer included in the study. The methodology adopted to compute efficiency scores originates from Färe et al. (2002). The production technology is here represented by the directional output distance function, which is defined to credit a simultaneous expansion of good outputs and contraction of emissions, i.e., bad outputs. The distance function is further specified using a quadratic flexible functional form and computed by a linear programming technique. In a second step, by regressing the resulting efficiency scores on a regulatory intensity index, approximating environmental stringency, the efficiency part of the Porter hypothesis is explicitly empirically tested. In this paper, the suggested test procedure is applied on 12 Swedish pulp plants during 1983-1990.

Hetemäki (1996) and Marklund (1999) explicitly test the efficiency part of the Porter hypothesis in a similar way. However, they apply a Shephard output distance function to compute the efficiency scores, which credits a simultaneous expansion of all outputs. This means that the producers are interpreted as becoming more efficient when increasing both good and bad outputs proportionally, which may be problematic in this context. Other studies that investigate the impacts of environmental regulation on efficiency, but not in the purpose of explicitly testing the Porter hypothesis, are Boyd and McClelland (1999) and Hernández-Sancho et al. (2000). They apply hyperbolic efficiency measures that assume producers to become more technically output efficient when they simultaneously increase good outputs and decrease bad outputs. However, the approach they adopt to analyze the impact of environmental regulation is based on the assumption that regulation either does not affect the producers or that

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[1] The empirical relationship between environmental policy and technological development is left aside. However, Jaffe et al. (2002) provide a thorough guide to the literature on this topic. Specifically, they provide an overview on analytical frameworks for investigating technological change. Furthermore, they turn their attention to theoretical analysis of the effects of environmental policy on technological change, and focus further on issues related to empirical analysis of technological change. See also Jaffe et al. (1995).

regulation causes efficiency losses. Then, by definition, there is no positive correlation between environmental regulation and efficiency. Therefore, this approach cannot be applied to test the efficiency part of the Porter hypothesis.

This paper tests the efficiency part of the Porter hypothesis by applying an output efficiency measure, i.e., the directional output distance function, where producers are assumed to become more efficient when they increase good outputs at the same time as decreasing bad outputs. In addition, the test procedure adopted does not, a priori, impose any restriction on the effects of environmental regulation on efficiency.

The paper is structured as follows. In the next section, an interpretation of the Porter hypothesis is outlined and, in addition, some theoretical research that criticizes or partly finds support for the hypothesis is reviewed. Section 3 briefly presents a theoretical foundation to measure technical output efficiency involving the directional output distance function. In Section 4 the empirical model is provided, starting with a parameterization of the distance function and ending with a description of the suggested test concerning the efficiency part of the Porter hypothesis. Section 5 presents the data, and Section 6 provides the empirical results. Finally, Section 7 summarizes and concludes.

2 THE PORTER HYPOTHESIS

The Porter hypothesis has been, and still is, subject to vivid debate. The discussion in the economic literature focuses not only on the general question of whether the hypothesis should be rejected or not, but also on the more delicate problem of how to interpret it. For instance, Jaffe and Palmer (1997) write: “More systematic economic analysis of the Porter hypothesis is hindered by ambiguity as to exactly what the hypothesis is” (p. 610). However, my interpretation of the Porter hypothesis, based on Porter and van der Linde (1995), is here outlined in Figure 1.

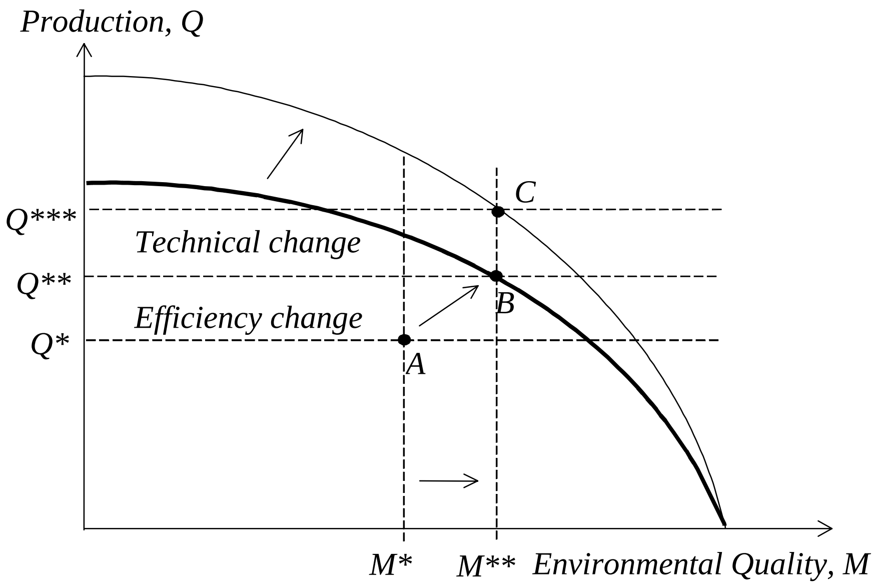

Figure 1 The Porter hypothesis

The production possibilities of the economy are initially defined as the output set within the bold curve. Given an environmental policy that demands an environmental quality of at least size M^*, the production possibility set will be confined to the area that is to the right of the vertical line M^* and within the bold curve. The Porter hypothesis means that if M^* represents a relatively lax environmental policy, the producers may be unaware of existing improvements that can be made. In the figure this is characterized by producing at point A, which means that the production of goods and services equals Q^*. At point A, it is technologically possible to produce more goods and services without using more inputs and worsening environmental quality. In other words, the producers are technically inefficient.

Now suppose that the environmental requirements are sharpened and that the environmental restriction moves from M^* to M^{**}. According to the hypothesis, this will make the producers aware of their own performance, reveal inefficiencies and give the producers an incentive to change their behavior. In Figure 1, this is illustrated by a movement from point A to point B. At point B, producer efficiency is higher than at point A, as the production of goods and services has increased from Q^* to Q^{**}. Furthermore, compliance costs due to the stricter environmental regulation also make environmentally friendlier technological development relatively less costly, which, in turn, generates better products, more developed processes and so on. This is represented by an outward shift of the production possibility curve, which means that with a given set of resources it is now possible to produce more goods and services without worsening the environmental quality or vice versa. These innovations enable the producers to move from point B to point C. The total effect on output from the stricter environmental requirement is then the sum of the efficiency gain (Q^{**}-Q^{*}) and the gain from technological innovations (Q^{***}-Q^{**}).

The Porter hypothesis has been heavily criticized by economists who argue that the hypothesis lacks theoretical foundation. The question commonly raised is why regulation actually is needed for producers to take privately beneficial measures. For instance, the objection in Palmer et al. (1995) is that producers always have the option to make environmentally friendly investments. The fact that they do not do so voluntarily reveals that they regard such investments as unprofitable. There is no free or even paid lunch, i.e., there are no $10 bills waiting to be picked up, as Porter and van der Linde (1995, p. 99) state. In addition, Palmer et al. (1995) mean that the argument of a free or even paid lunch diverts attention from the cost-benefit analysis of environmental policy, which is highly necessary from a societal point of view.

However, there are theoretical papers that partly find support for the Porter hypothesis. Following the hypothesis, the papers discussed below are all based on the assumption that newer capital is more productive and less polluting than older capital. In Xepapadeas and de Zeeuw (1999) the exogenous shock from an emission tax per unit of emissions induces the firm to reach for new available technology, which then is relatively less costly. Within an infinite horizon optimal control problem, where the firm maximizes profits, they show that stricter environmental policy cannot be expected to provide a ‘win-win’ situation in the sense of increasing both environmental quality and the firm’s profitability. However, even though the stricter policy causes the total capital stock to shrink (downsizing effect), the ensuing capital investments reduce the average age of the capital stock and, thus, increase its productivity (modernization effect). Furthermore, within a general equilibrium framework, Mohr (2002) provides a learning-by-doing model, which shows that endogenous technological change makes the Porter hypothesis feasible. The productivity of any given firm depends on the cumulative production experience of all firms using the same (old) technology. In this model external economies of scale in production prevent the individual firm from adopting a newer, already available, technology. The reason is that employees have less experience of the new technology, which then initially would lower the firm's productivity and, therefore, cause short-run costs in terms of lost competitiveness. The result in Mohr (2002) shows that if the government pursues an environmental policy that requires all firms to adopt the newer technology, then the policy could both improve environmental quality and increase beneficial output, as employees in the long-run reach a sufficient experience of that technology. Finally, within the scope of game theory, involving a division manager and a firm (shareholders) that maximize private utility, and a social welfare maximizing regulator that grants maximally allowed emission levels, Ambec and Barla (2002) show that the Porter hypothesis is likely to be valid under certain circumstances. Regulation is found to have a positive impact on investment in R&D since the marginal benefit to investment increases. One condition that then contributes to the validity of the hypothesis is a high likelihood that the R&D program generates a cleaner technology that also brings a sufficiently high marginal productivity gain.

The results in Xepapadeas and de Zeeuw (1999), Mohr (2002), and Ambec and Barla (2002) indicate that the assumption of imperfect information is not crucial to derive results consistent with the Porter hypothesis. Furthermore, these papers focus on technological change (when assuming maximization behavior), which in Figure 1 is represented by an outward shift of the production possibility curve. However, Porter and van der Linde (1995) argue that firms, of course, do not always make optimal choices, and that competition is characterized by: "(…) organizational inertia and control problems reflecting the difficulty of aligning individual, group and corporate incentives" (p. 99). In this paper, this is interpreted such that resources may not be optimally utilized and, therefore, there exists intrafirm technical output inefficiency, which, in Figure 1, answers to point A. According to the Porter hypothesis environmental regulation induces firms operating at point A to move towards the production possibility frontier, e.g., to point B. To develop a procedure for an empirical test of the significance of this particular hypothesis, a theoretical foundation to measure technical output efficiency is first given in the next section.

3 THEORY

The directional output distance function approach adopted to estimate technical output efficiency originates from Färe et al. (2002). Formally, let $y = (y_1,...,y_M) \in \Re_+^M$ and $b = (b_1,...,b_J) \in \Re_+^J$ be vectors of good outputs and bad outputs, respectively, and let $x = (x_1,...,x_N) \in \Re_+^N$ be a vector of inputs. The technology of reference is the output possibilities set, $P(x)$, which, for a given vector of inputs, denotes all technically feasible output vectors. The output set is assumed to be convex and compact with $P(0) = \{0,0\}$. Furthermore, inputs and good outputs are assumed to be freely disposable and bad outputs only weakly disposable. Finally, good outputs are assumed to be null-joint with the bad outputs. The directional output distance function is defined on $P(x)$ as

$$D(x, y, b; g) = \max_{\beta} \{\beta : (y + \beta \cdot g_y, b - \beta \cdot g_b) \in P(x)\} \tag{1}$$

which inherits its properties from $P(x)$. The solution, β^*, gives the maximum expansion and contraction of good outputs and bad outputs, respectively. The vector $g = (g_y, -g_b)$ specifies in what direction an output vector, $(y,b) \in P(x)$, is scaled so as to reach the boundary of the output set at $(y + \beta^* \cdot g_y, b - \beta^* \cdot g_b) \in P(x)$, where $\beta^* = D(x, y, b; g)$. This means that the producer becomes more efficient when simultaneously increasing good outputs and decreasing bad outputs.[2] The directional output distance function takes the value of zero for technically efficient output vectors on the boundary of $P(x)$,

[2] In this paper, the directional vector *g* = (1,-1) is chosen for the sake of simplicity. An alternative would be to choose the vector *g* = (*y*,-*b*), which has been done when estimating the directional output distance function by non-parametric linear techniques, see, e.g., Chung et al. (1997).

whereas positive values apply to technically inefficient output vectors below the boundary. The higher the value the more inefficient the output vector.

4 THE EMPIRICAL MODEL

4.1 The functional form of the distance function

Following Färe et al. (2002), the directional output distance function is parameterized by using a (additive) quadratic flexible functional form, which for producer k in time period t is written as

$$\begin{aligned} D^{kt}\left(x^{kt}, y^{kt}, b^{kt}; g\right) = \alpha_0 &+ \sum_{n=1}^{N} \alpha_n x_n^{kt} + \sum_{m=1}^{M} \beta_m y_m^{kt} + \sum_{j=1}^{J} \gamma_j b_j^{kt} \\ &+ \frac{1}{2} \sum_{n=1}^{N} \sum_{n'=1}^{N} \alpha_{nn'} x_n^{kt} x_{n'}^{kt} + \sum_{n=1}^{N} \sum_{m=1}^{M} \delta_{nm} x_n^{kt} y_m^{kt} + \sum_{n=1}^{N} \sum_{j=1}^{J} \eta_{nj} x_n^{kt} b_j^{kt} \\ &+ \frac{1}{2} \sum_{m=1}^{M} \sum_{m'=1}^{M} \beta_{mm'} y_m^{kt} y_{m'}^{kt} + \sum_{m=1}^{M} \sum_{j=1}^{J} \mu_{mj} y_m^{kt} b_j^{kt} \\ &+ \frac{1}{2} \sum_{j=1}^{J} \sum_{j'=1}^{J} \gamma_{jj'} b_j^{kt} b_{j'}^{kt} \\ &+ \kappa_k + \tau_t \end{aligned} \tag{2}$$

where κ and τ represent producer and time specific effects, respectively. Equation (2) will be estimated by a linear programming technique, subject to restrictions that impose the properties inherited from $P(x)$ briefly mentioned above.[3]

4.2 Testing the Porter hypothesis

Once the technical output efficiency scores for each individual producer, k, in each period, t, are estimated, parametric tests on different hypotheses regarding the variability in efficiency can be performed. A general model for testing the Porter hypothesis is formulated as follows

[3] The particular estimation approach applied is described in detail in Marklund (2003). See also Färe et al. (2002).

$$ED^{kt}(\cdot) = \phi + \sum_{j=1}^{J} \omega_j R_j^{kt} + \rho_k + \psi_t + \varepsilon^{kt} \qquad (3)$$

where $ED^{kt}(\cdot)$ is the previously estimated technical output efficiency of producer k in time period t, R_j represents the intensity of pursued environmental policy regarding the $j:th$ bad output, while ρ_k and ψ_t represent plant specific effects and time specific effects, respectively.[4] The last term on the right-hand side, ε, is an error term that is uncorrelated with all other right-hand side variables and uncorrelated in time and across plants. The parameters to be estimated are ϕ, ω_j, where $j = 1,..., J$, ρ_k, where $k = 2,..., K$, and ψ_t, where $t = 2,...,T$. Performing t-tests on the estimates of ω_j is synonymous with testing the Porter hypothesis.

To approximate the stringency of pursued environmental policy, a regulatory intensity measure is used. Gollop and Roberts (1983) developed an intensity measure divided into two parts, one measuring the severity of emission standards and the other measuring the standards' extent of enforcement. The enforcement part reflects the degree to which actual emission levels correspond to maximally allowed levels and, therefore, also accounts for the possibility that a producer may fail to comply with a standard. However, since emissions are included as bad outputs in the directional output distance function, the enforcement factor is embedded in its parameter estimates. For instance, shadow prices of bad outputs derived from this function are indicators of how producers perceive emission standards (see, e.g., Färe et al., 2002; Marklund, 2003). Therefore, the intensity of pursued environmental policy is here approximated using only the severity part of the Gollop and Roberts (1983) measure. Accordingly, the environmental regulatory intensity index concerning the *j:th* bad output is calculated for each producer as

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[4] An alternative to the plant specific effects, i.e., the fixed effects, would be to model random effects. However, the random effects model was rejected in this case since the fixed effects model explains technical output efficiency to a much greater extent.

$$R_j^{kt} = \left(\frac{b_j^{DES,k} - b_J^{MAX,kt}}{b_j^{DES,k}} \right), \qquad j = 1,...,J, \quad R_j \in [0,1] \tag{4}$$

where $b_j^{DES,k}$ is the desired, or unconstrained, emission rate for producer *k*, and $b_j^{MAX,kt}$ is the maximally allowed emission rate for producer *k* in period *t*.[5] The regulatory index measures, as a percentage, the difference between the unconstrained emission rate and the maximally allowed emission rate that are imposed on the producers. When no emission is allowed $b_j^{MAX} = 0$ and R_j is set to unity, which means that the authorities consider it best to shut down the production.[6] In contrast, R_j is bounded from below by zero, reflecting that maximally allowed emission equals desired emission, $b_j^{MAX} = b_J^{DES}$.[7] In this case the emission standards have no effect on the environment.

5 DATA

The directional output distance function is estimated using data on the Swedish pulp and paper industry gathered by Statistics Sweden and the Swedish Environmental Protection Agency. The data set available is an unbalanced panel that contains annual information on 12 plants producing pulp. It extends over the period 1983-1990, with a total of 86 observations. To produce the good output, pulp, y_1, each plant is assumed to use four inputs; wood fiber, x_1, labor, x_2, electricity, x_3, and capital, x_4. Simultaneously produced bad outputs, landing in surrounding waters, are oxygen-demanding substances, b_1, and suspended solids, b_2. More detailed information on inputs and outputs is provided in Marklund (2003).

For the purpose of testing the Porter hypothesis in accordance with equation (3), some additional information must be considered. A substantial part of the

[5] Desired and maximally allowed emission levels are further commented on in Section 5.
[6] As mentioned in Section 3, the good outputs are null-joint with the bad outputs. This means that good outputs cannot be produced without producing bad outputs.
[7] It is assumed that b^{MAX} cannot exceed b^{DES}.

emissions into the Gulf of Bothnia, the Bothnian Sea, and the Baltic Sea originates from the pulp and paper industry. To ensure a better quality of these waters, the National Licensing Board of Environment Protection, active during the period under study, granted the plants non-tradable emission permits.[8] Thus, the plants are in each year constrained by maximally allowed emission levels of oxygen-demanding substances, b_1^{MAX}.[9] This information is used in the construction of the environmental regulatory intensity index in equation (4). Furthermore, the index demands data on the desired emission level for every plant, b_1^{DES}, which here is assumed to equal each plant's highest emission level that is observed in the sample.[10] Descriptive statistics for the variables used to test the Porter hypothesis are provided in Table A1 in the Appendix.

6 RESULTS

The directional output distance function is estimated using mean normalized input and output data.[11] The estimated values of the function are technical output efficiency scores for all of the 86 observations. Table 1 provides these scores in the form of arithmetic averages for each plant, for the whole sample, and at mean of the data. Regulatory intensity concerning oxygen-demanding substances, calculated in accordance with equation (4), is also provided.

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[8] Regarding this particular procedure, see Marklund (2003).

[9] Due to lack of data, the Porter hypothesis is not tested for restrictions on discharges of suspended solids.

[10] Each plant's desired emission level could be derived from the estimated distance function, by letting $(\partial D/\partial b_1)/(\partial D/\partial y_1) = 0$, i.e., letting the marginal abatement cost of b_1 in terms of y_1 be zero, and then solve for b_1. In this study the resulting desired emission levels for oxygen-demanding substances are on average about 33 times higher (about 16 times higher if one particular plant is excluded) than actually observed emission levels. Whether this is in accordance with reality or not is left unanswered. However, independently of which of the definitions of desired emission level that is adopted, the outcome of the Porter hypothesis test performed in this paper is roughly the same.

[11] The parameter estimates are provided in Marklund (2003), Table A3, where exactly the same estimating procedure is applied on the same data as in this paper.

Table 1 Technical efficiency scores and environmental regulatory intensity values for mean normalized variable quantities (standard deviations in parentheses)

Plant	**Efficiency scores ED(.)**	**Regulatory intensity R_1**
1	0.026 (0.036)	0.271 (0.290)
2	0.004 (0.008)	0.080 (0.103)
3	0.017 (0.018)	0.371 (0.046)
4	0.022 (0.016)	0.593 (0.088)
5	0.033 (0.026)	0.409 (0.012)
6	0.006 (0.006)	0.000 (0.000)
7	0.023 (0.031)	0.451 (0.049)
8	0.016 (0.022)	0.215 (0.397)
9	0.030 (0.034)	0.610 (0.064)
10	0.040 (0.047)	0.665 (0.160)
11	0.066 (0.041)	0.523 (0.037)
12	0.044 (0.052)	0.297 (0.278)
Average	0.027 (0.033)	0.378 (0.263)
At mean	0.118	-

For the hypothetical plant that during 1983-1990 used the sample mean of inputs to produce the sample mean of outputs, the estimated value of the distance function, 0.118, indicates a technical output inefficiency of 11.8 percent. This means that, without changing input quantity and/or developing technology, the ‘at mean’ producing plant could increase the production of pulp with 255.5*0.118 = 30.15 thousand tons, while simultaneously decreasing the production of oxygen-demanding substances and suspended solids with 34.9*0.118 = 4,12 and 1.8*0.118 = 0.21 thousand tons, respectively.[12] In addition, the average inefficiency ranges between plants from a low of 0.004 to a high of 0.066, and for the whole sample the corresponding figure is 0.027. This indicates that there is a possible ‘win-win’ potential to increase production and reduce pollution, as suggested by the Porter hypothesis. Furthermore, environmental regulatory

[12] Remember that the distance function is estimated on mean normalized data, and that the mean quantity of pulp is 255.5 thousand tons, of oxygen-demanding substances is 34.9 thousand tons, and of suspended solids is 1.8 thousand tons.

intensity ranges from a low of 0.000 to a high of 0.665. The latter value is interpreted such that the regulatory authority wants to reduce the emission level with 66.5 percent compared to the plant's desired emission level. The corresponding average figure for the whole sample is 37.8 percent.

The Porter hypothesis test is performed in accordance with the model in (3), and the outcome of regressing estimated technical output efficiency scores, $ED(\cdot)$, on calculated regulatory intensity index and dummy variables capturing plant specific effects is presented in Table 2.[13]

Table 2 The Porter hypothesis test

Coefficient	**Variable**	**Estimate**	**t-value**
ϕ	*intercept*	0.0298	2.4240
ω_1	*regulatory index, R_1*	-0.0142	-0.7143
ρ_2	*plant 2*	-0.0249	-1.4954
ρ_3	*plant 3*	-0.0075	-0.4602
ρ_4	*plant 4*	0.0003	0.0200
ρ_5	*plant 5*	0.0091	0.5701
ρ_6	*plant 6*	-0.0238	-1.3381
ρ_7	*plant 7*	-0.0004	-0.0252
ρ_8	*plant 8*	-0.0111	-0.7061
ρ_9	*Plant 9*	0.0090	0.5271
ρ_{10}	*plant 10*	0.0198	1.1002
ρ_{11}	*plant 11*	0.0436	2.4684
ρ_{12}	*plant 12*	0.0184	1.1316
Adjusted R-squared		0.1059	
Number of observations		86	

If maximally allowed emission levels of oxygen-demanding substances are lowered, the regulatory intensity, R_1, will increase. As can be noted from the estimated coefficient, ω_1, this will increase efficiency in the sense that the value of $ED(\cdot)$ decreases. However, this particular coefficient of the regulatory

[13] None of the time dummy variables are significant and are therefore excluded, resulting in a higher adjusted R-squared value. A time trend hypothesis was also tested and rejected.

intensity is not significantly different from zero and, therefore, the conclusion is that the result shows no support for the Porter hypothesis. That is, the test provides no evidence that environmental standards made the Swedish pulp plants under study more resource efficient during 1983-1990. However, the opposite cannot be concluded either, i.e., that regulation made the plants more resource inefficient.

7 SUMMARY AND CONCLUSION

This paper is devoted to proposing a procedure to empirically test the Porter hypothesis, introduced in Porter (1991) and further developed in Porter and van der Linde (1995). The dominating argument of the hypothesis is that environmental regulation not only increases environmental quality, but also provides information, which makes the producers more aware of state of productivity and possibilities to improve competitiveness. The productivity change is divided into an efficiency change and a technological change.

The procedure suggested is general in the sense that it can be applied to any production process at the firm, industry, or country level. It provides a tool to study the efficiency part of the Porter hypothesis, which argues that producers use resources inefficiently and that environmental regulation sends signals about these inefficiencies and induces them to change their behavior. The hypothesis may be empirically analyzed by testing whether there is a positive significant correlation between producers’ technical output efficiency and environmental regulation.

Technical output efficiency is first estimated using a methodology that originates from Färe et al. (2002). The production technology is here represented by the directional output distance function, which is defined to credit a simultaneous expansion of good outputs and contraction of bad outputs. This means that a producer is interpreted as becoming more efficient when increasing the production of the market goods at the same time as emissions are decreased, given input quantity and technology. The distance function is further specified using a quadratic flexible functional form and computed by a linear programming technique. Then, by regressing the obtained efficiency scores on environmental regulatory stringency, approximated by a regulatory intensity index that measures the difference between the unconstrained and the maximally allowed emission rate, the Porter hypothesis is explicitly tested.

The suggested test procedure is applied on 12 Swedish pulp plants during 1983-1990. The result shows no support for the Porter hypothesis. That is, the test provides no evidence that environmental regulation made the pulp plants more resource efficient during the period under study.

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APPENDIX

Table A1 Definitions and mean statistics for variables included in the Porter hypothesis test (standard deviations in parentheses)

Variable	1983	1984	1985	1986	1987	1988	1989	1990
R_1	0.305 (0.297)	0.332 (0.263)	0.340 (0.267)	0.346 (0.277)	0.360 (0.264)	0.386 (0.273)	0.486 (0.254)	0.515 (0.209)
ED(.)	0.016 (0.029)	0.024 (0.028)	0.036 (0.039)	0.026 (0.027)	0.023 (0.031)	0.034 (0.044)	0.027 (0.035)	0.027 (0.037)

Variable	1983-1990		
	mean	min	max
R_1	0.378 (0.263)	0.000	0.859
ED(.)	0.027 (0.033)	0.000	0.132

R_1 = environmental regulatory intensity index for mean normalized quantities of oxygen-demanding substances

$ED(\cdot)$ = estimated technical output efficiency scores for mean normalized variable quantities; y_1 = pulp, 255.5 thousand tons, b_1 = biological and chemical oxygen-demanding substances, 34.9 thousand tons, b_2 = suspended solids, 1.8 thousand tons